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(54) **STEEL FOR WELDED STRUCTURE AND PRODUCING METHOD THEREOF**

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C21D 8/00	(2006.01)

(52) **U.S. Cl.**

USPC **148/336**; 148/332; 148/541; 148/546; 148/547; 148/648; 420/126; 420/128; 420/119

(58) **Field of Classification Search**

USPC 420/126, 128, 119; 148/320, 332, 336, 148/541, 546, 547, 648

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,790,885	A	12/1988	Imagumbai et al.
5,985,053	A	11/1999	Hara et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CA	2 231 985	9/1998
CA	2 429 439	11/2003

(Continued)

OTHER PUBLICATIONS

Machine-English translation of Japanese patent 2008-169429, Chijiiwa Rikio et al., Jul. 24, 2008.*

(Continued)

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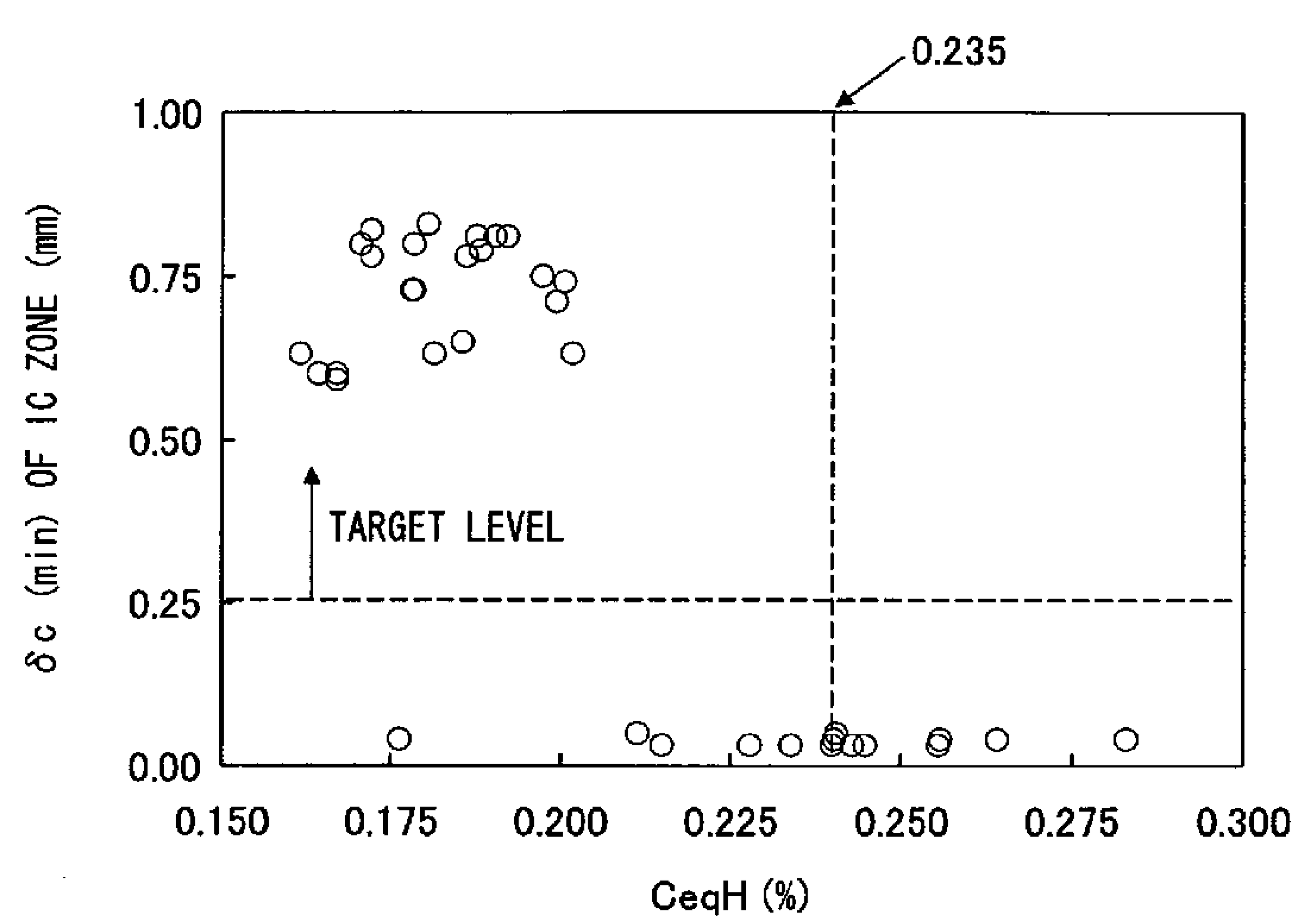
(57) **ABSTRACT**

A steel for a welded structure includes the following composition: by mass %, C at a C content [C] of 0.015 to 0.045%; Si at a Si content [Si] of 0.05 to 0.20%; Mn at a Mn content [Mn] of 1.5 to 2.0%; Ni at a Ni content [Ni] of 0.10 to 1.50%; Ti at a Ti content [Ti] of 0.005 to 0.015%; O at an O content [O] of 0.0015 to 0.0035%; and N at a N content [N] of 0.002 to 0.006%, and a balance composed of Fe and unavoidable impurities. In the steel for a welded structure, the P content [P] is limited to 0.008% or less, the S content [S] is limited to 0.005% or less, the Al content [Al] is limited to 0.004% or less, the Nb content [Nb] is limited to 0.005% or less, the Cu content [Cu] is limited to 0.24% or less, the V content [V] is limited to 0.020% or less, and a steel composition parameter P_{CTOD} is 0.065% or less, and a steel composition hardness parameter CeqH is 0.235% or less.

5 Claims, 4 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,224,689	B1	5/2001	Koo et al.
6,248,191	B1	6/2001	Luton et al.
2003/0116238	A1	6/2003	Fujita et al.
2004/0031544	A1	2/2004	Hara et al.
2007/0051433	A1	3/2007	Kamo et al.
2007/0181223	A1	8/2007	Ito et al.
2010/0008815	A1	1/2010	Chijiiwa et al.
2012/0027637	A1	2/2012	Watanabe et al.

FOREIGN PATENT DOCUMENTS

CA	2 602 076	6/2008
EP	1094126	4/2001
EP	1143023	10/2001
EP	1221493	7/2002
EP	1695785	8/2006
EP	1 736 562	12/2006
EP	2 060 643	5/2009
JP	54-131522	10/1979
JP	62-240747	10/1987
JP	01-159356	6/1989
JP	04-103742	4/1992
JP	05-171341	7/1993
JP	07-278653	10/1995
JP	09-003590	1/1997
JP	9-3597	1/1997
JP	09-157787	6/1997
JP	09-279235	10/1997
JP	10-298708	11/1998
JP	11-279684	10/1999
JP	2000-096139	4/2000
JP	2000-345286	12/2000
JP	2001-323336	11/2001
JP	2002-030380	1/2002
JP	2004-162150	6/2004
JP	2005-256161	9/2005
JP	2007-002271	1/2007
JP	2008-163446	7/2008
JP	2008-169429	7/2008
KR	10-2002-0028203	4/2002
KR	2006-0090287	6/2005
RU	2135622	8/1999
RU	2136775	9/1999
RU	2198771	2/2003
RU	2210603	8/2003
RU	2211877	9/2003
RU	2215813	11/2003
WO	01/86013	11/2001
WO	2009/072663	6/2009

OTHER PUBLICATIONS

International Search Report dated Aug. 10, 2010 issued in corresponding PCT Application No. PCT/JP2010/003344.

Canadian Office Action dated Oct. 11, 2011 issued in corresponding Canadian Patent Application No. 2,749,154.

European Search Report dated Jun. 19, 2012, issued in corresponding European Patent Application No. 10777561.1.

Notice of Allowance dated Mar. 2, 2012, issued in corresponding Russian Patent Application No. 2011129331, with an English translation thereof.

European Search Report dated Jun. 29, 2011, issued in corresponding European Patent Application No. 08856343.

International Search Report dated Feb. 10, 2009, issued in corresponding International Patent Application No. PCT/JP2008/072461.

Final Office Action dated Sep. 6, 2011, issued in U.S. Appl. No. 12/448,582 corresponding to US 2010/0008815.

Non-Final Office Action dated Apr. 6, 2011, issued in U.S. Appl. No. 12/448,582 corresponding to US 2010/0008815.

European Search Report dated Sep. 19, 2012 issued in corresponding European Application No. 10 77 7589.

Russian Notice of Allowance, dated Jul. 3, 2012, issued in corresponding Russian application No. 2011146832, with an English translation thereof.

Korean Office Action, dated Jan. 2, 2012, issued in corresponding Korean application No. 10-2011-7009636, with English translation.

Canadian Office Action, dated Jan. 25, 2012, issued in corresponding Canadian application No. 2,757,223.

International Search Report dated Aug. 10, 2010 issued in corresponding PCT Application No. PCT/JP2010/003435 [With English Translation].

Computer-generated translation of JP 09-279235, originally published in the Japanese language on Oct. 28, 1997.

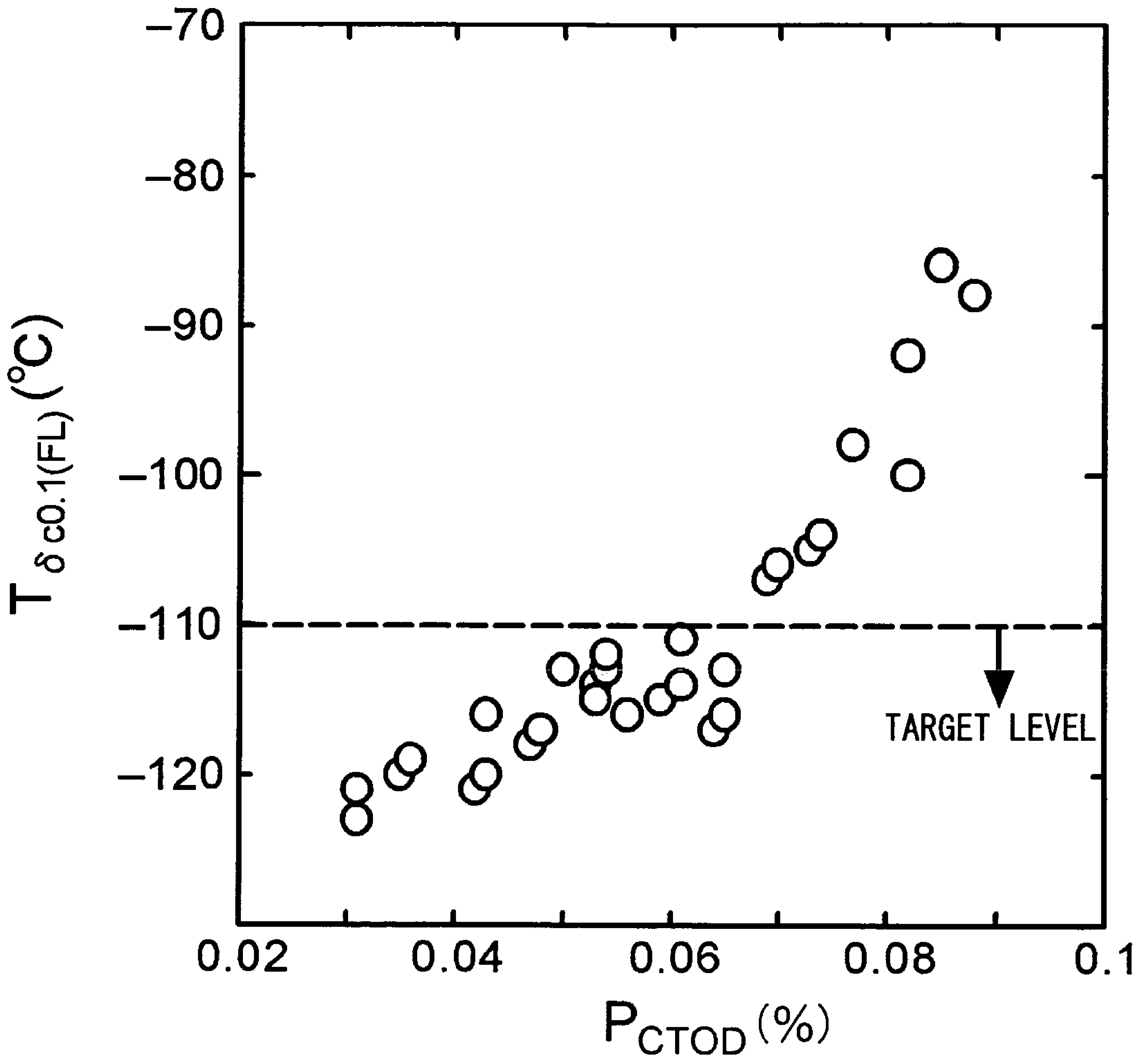
Computer-generated translation of JP 2005-256161, originally published in the Japanese language on Sep. 22, 2005.

Office Action dated May 28, 2013 from related U.S. Appl. No. 13/138,790.

Office Action dated Nov. 26, 2012 from related U.S. Appl. No. 13/138,790.

* cited by examiner

FIG. 1



−70
−80
−90
−100
−110
−120
$T_{\delta c0.1(FL)}$ (°C)
TARGET LEVEL
0.02
0.04
0.06
0.08
0.1
P_{CTOD} (%)

FIG. 2

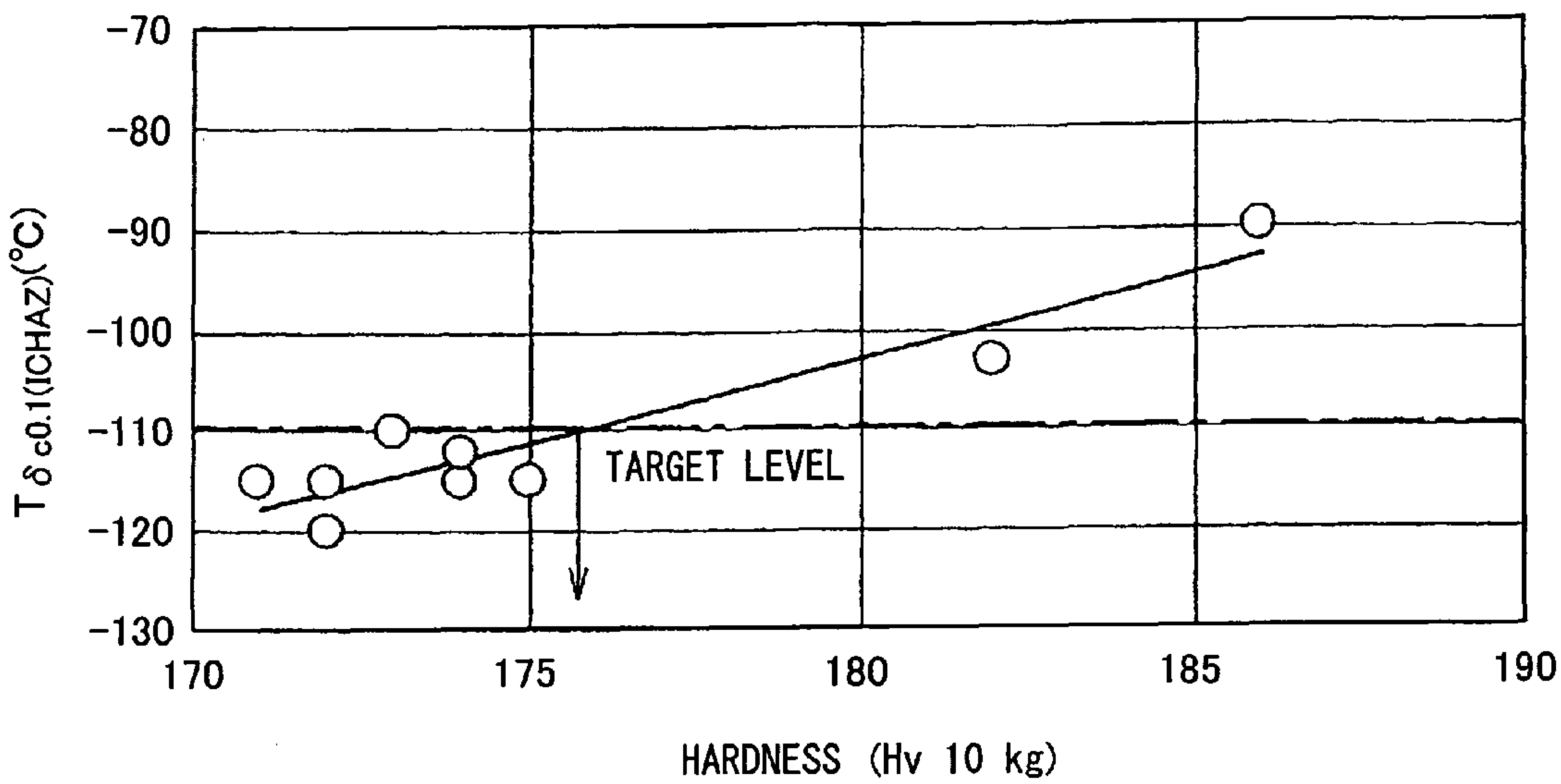

-70
-80
-90
-100
-110
-120
-130
Tδc0.1(ICHAZ)(°C)
TARGET LEVEL
170
175
180
185
190
HARDNESS (Hv 10 kg)

FIG. 3

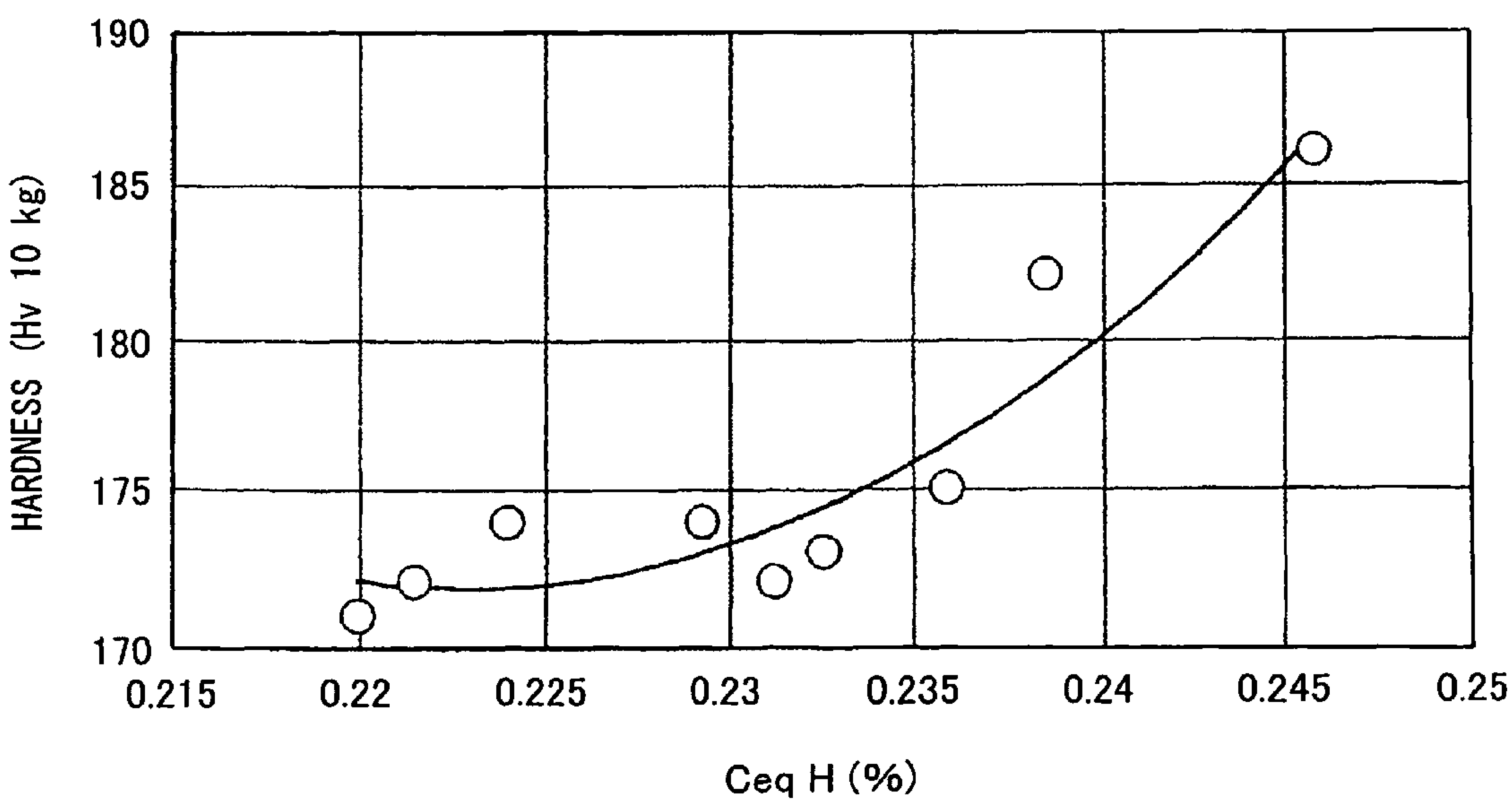

190
185
180
175
170
HARDNESS (Hv 10 kg)
0.215
0.22
0.225
0.23
0.235
0.24
0.245
0.25
Ceq H (%)

FIG. 4A

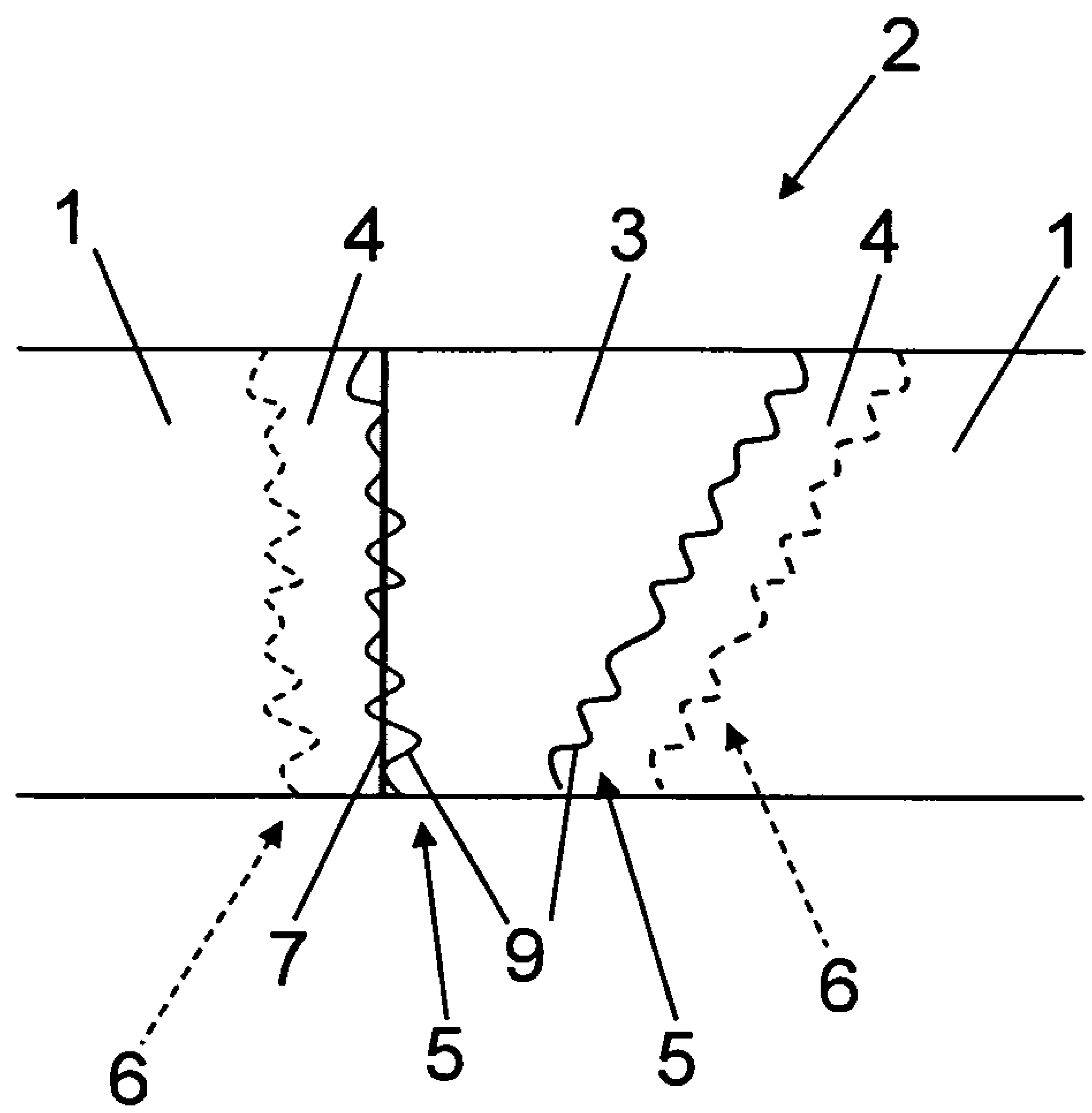


FIG. 4B

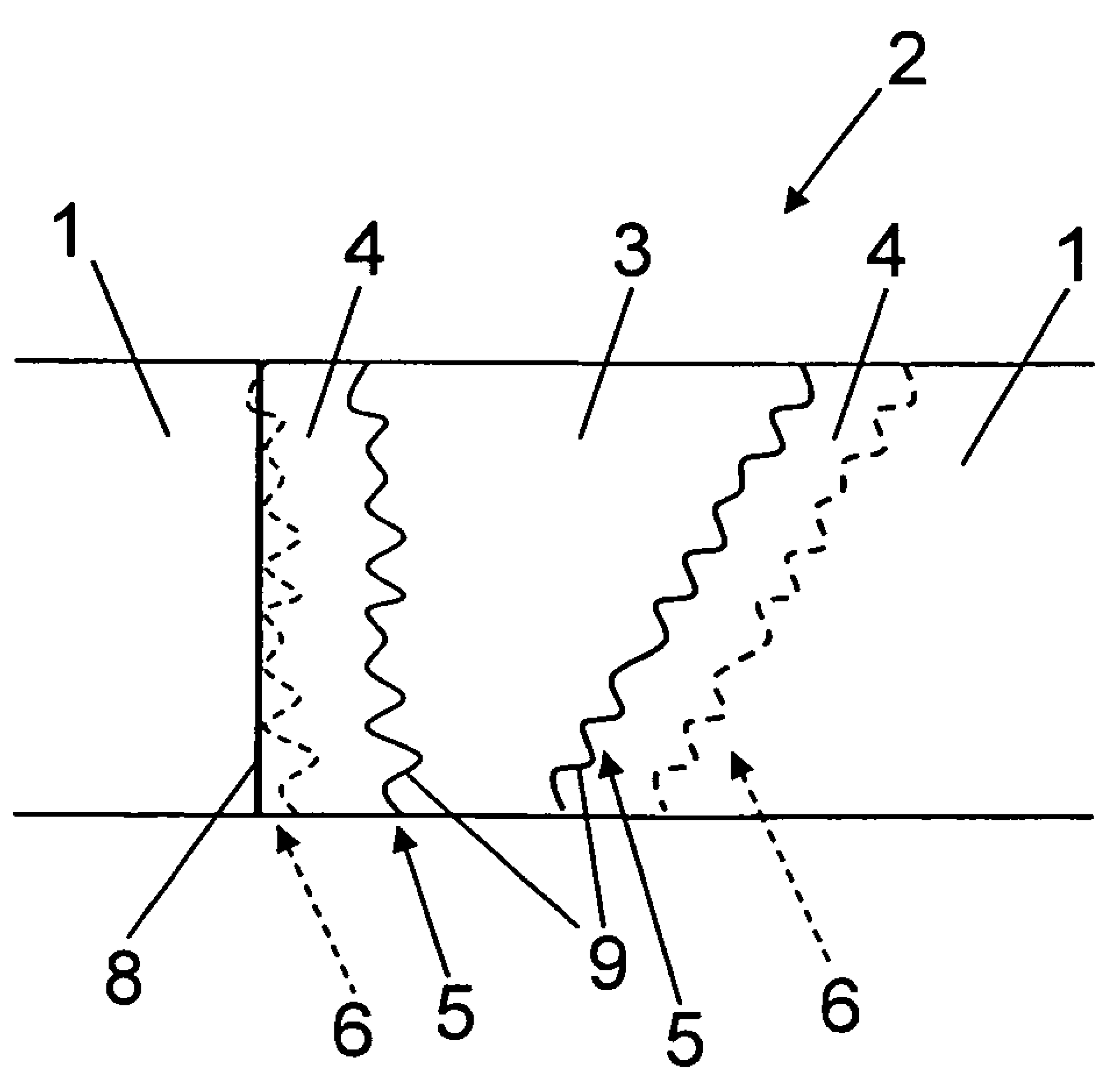
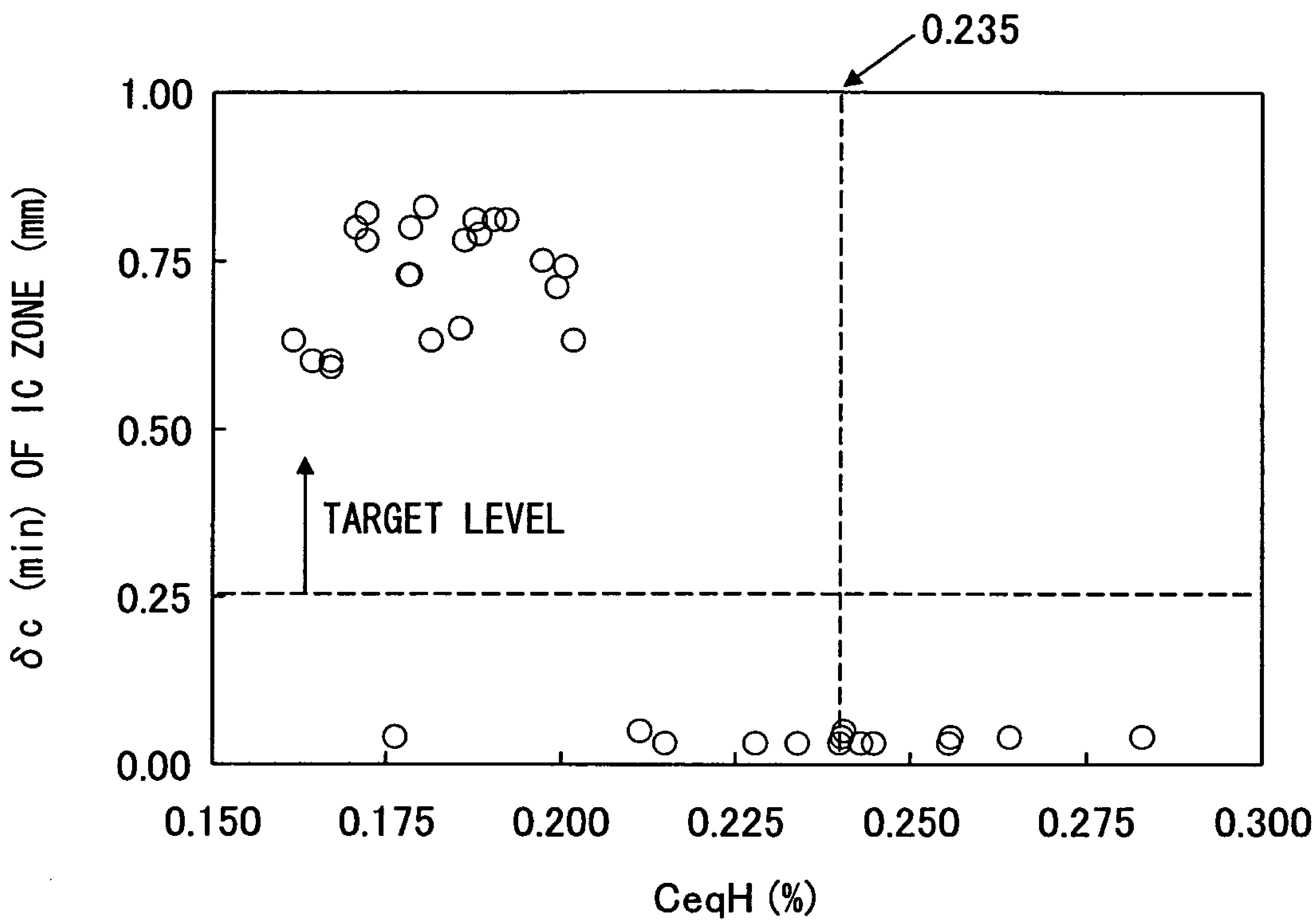


FIG. 5


0.235
1.00
0.75
0.50
0.25
0.00
δc (min) OF IC ZONE (mm)
TARGET LEVEL
0.150
0.175
0.200
0.225
0.250
0.275
0.300
CeqH (%)

STEEL FOR WELDED STRUCTURE AND PRODUCING METHOD THEREOF

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a steel for a welded structure superior in a CTOD property of a heat affected zone (HAZ) in a low heat input welding to a medium heat input welding, and a producing method thereof. Particularly, the present invention relates to a steel for a welded structure far superior in a CTOD property of an FL zone and an IC zone where toughness deteriorates the most in a low heat input welding to an medium heat input welding, and a producing method thereof.

This application is a national stage application of International Application No. PCT/JP2010/003344, filed on May 18, 2010, which claims priority to Japanese Patent Application No. 2009-121128, filed May 19, 2009 and Japanese Patent Application No. 2009-121129, filed May 19, 2009, the contents of which are incorporated herein by reference.

2. Description of Related Art

In recent years, there has been a demand for a steel for use in harsh environments. For example, as high-strength steel suitable for steel structures such as offshore structures used in a frigid sea area such as the Arctic region, and seismic resistant structures, there is a need for a steel excellent in a CTOD (Crack Tip Opening Displacement) property which is one of facture toughness parameters. In particular, the weld of the steel needs an excellent CTOD property.

The CTOD property of the heat affected zone (HAZ) is evaluated by test results of two positions (notch section) of an FL zone "Fusion Line: a boundary of a WM (weld metal) and an HAZ (heat affected zone)" and an IC zone "Intercritical HAZ: a boundary of an HAZ and a BM (base metal)". However, only the FL zone considered to obtain the lowest CTOD property has been evaluated in the past.

In conditions where a test temperature is not particularly harsh, for example, −20° C., if the CTOD property of the FL zone is sufficient, the CTOD property of the IC zone is also sufficient, such that it is not necessary to evaluate the CTOD property of the IC zone.

However, under harsh test conditions, for example, −60° C., there are many cases where a CTOD value of the IC zone is not sufficient, such that it is necessary to increase the CTOD property of the IC zone.

In this respect, techniques that is superior in the CTOD property of low heat input to medium heat input welded joint at a harsh test temperature (for example, −60° C.) are disclosed (for example, refer to Patent Citation 1 and Patent Citation 2). However, in these techniques, the CTOD property of the IC zone is not disclosed.

In the above-described techniques, for example, as transformation nuclei for the generation of an intragranular ferrite (IGF) in the FL zone, a relatively large amount of 0 is contained in steel for securing a sufficient amount of Ti-oxides. In addition, for example, for making a microstructure fine after welding, an element, which stabilizes austenite and increases hardenability, is added in a constant amount or more. However, in this method, it is difficult to secure the CTOD value of the IC zone of the steel in a harsh environment of about −60° C. while securing properties (for example, the strength or toughness of a base metal, and the CTOD value of the FL zone) necessary for a structural material for welded structure.

[Patent Citation 1] Japanese Unexamined Patent Application, First Publication No. 2007-002271

[Patent Citation 2] Japanese Unexamined Patent Application, First Publication No. 2008-169429

SUMMARY OF THE INVENTION

Here, the present invention provides a high-strength steel having an excellent CTOD (fracture toughness) property where the CTOD property of the IC zone is also sufficient in addition to the property of the FL zone at −60° C., in welding (for example, multilayer welding) of a low heat input to a medium heat input (for example, 1.5 to 6.0 kJ/mm at a plate thickness of 50 mm), and a producing method thereof.

The inventors made a thorough investigation of a method for improving a CTOD property of both an FL zone and an IC zone that are a weld where toughness deteriorates the most in welding of a low heat input to a medium heat input.

As a result, the inventors found that for improving the CTOD property of both the FL zone and IC zone, it is the most important to reduce non-metallic inclusions, specifically, it is essential to reduce O (oxygen in steel). In addition, the inventors found that since intragranular ferrite (IGF) decreases due to the reduction of O, it is necessary to reduce an alloy element that deteriorates the CTOD property of the FL region. Furthermore, the inventors found that for improving the CTOD property of the IC region, a reduction in hardness is effective in addition to the reduction of the oxygen in steel. From the findings, the inventors completed the present invention.

The summary of the present invention is as follows.

(1) A steel for a welded structure includes the following composition: by mass %, C at a C content [C] of 0.015 to 0.045%; Si at a Si content [Si] of 0.05 to 0.20%; Mn at a Mn content [Mn] of 1.5 to 2.0%; Ni at a Ni content [Ni] of 0.10 to 1.50%; Ti at a Ti content [Ti] of 0.005 to 0.015%; O at an O content [O] of 0.0015 to 0.0035%; and N at a N content [N] of 0.002 to 0.006%, and a balance composed of Fe and unavoidable impurities. In the steel, the P content [P] is limited to 0.008% or less, the S content [S] is limited to 0.005% or less, the Al content [Al] is limited to 0.004% or less, the Nb content [Nb] is limited to 0.005% or less, the Cu content [Cu] is limited to 0.24% or less, the V content [V] is limited to 0.020% or less, and a steel composition parameter P_{CTOD} of the following equation (1) is 0.065% or less, and a steel composition hardness parameter CeqH of the following equation (2) is 0.235% or less.

(2) In the steel for a welded structure according to (1), by mass %, the Cu content [Cu] may be 0.03% or less.

(3) In the steel for a welded structure according to (1) or (2), both a CTOD (δc) value in an FL zone at −60° C. and a CTOD (δc) value in an IC zone at −60° C., which are obtained by a CTOD test of BS 5762 method, may be 0.25 mm or more.

(4) A producing method of a steel for welded structure includes continuously casting steel satisfying the steel composition according to (1) or (2) to manufacture a slab; and heating the slab to a temperature of 950 to 1100° C. and then subjecting the slab to a thermo-mechanical control process.

According to the present invention, it is possible to provide a steel excellent in HAZ toughness in welding of a low heat input to a medium heat input. Particularly, it is possible to provide a steel excellent in a CTOD property (low-temperature toughness) of an FL zone and an IC zone where toughness deteriorates the most in welding, such as multilayer welding, of the low heat input to the medium heat input. Therefore, it is possible to provide a high-strength and high-toughness steel for a structure such as offshore structures and seismic resistant structures used in a harsh environment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a relationship between a steel composition parameter P_{CTOD} and a CTOD property ($T_{\delta c0.1(FL)}$) in a synthetic FL test using simulated thermal cycle.

FIG. **2** is a diagram illustrating a relationship between HAZ hardness and a CTOD property $T_{\delta c0.1(ICHAZ)}$ in a synthetic ICHAZ test using simulated thermal cycle.

FIG. **3** is a diagram illustrating a relationship between a steel composition hardness parameter CeqH and HAZ hardness in a synthetic ICHAZ test using simulated thermal cycle.

FIG. **4**A is a schematic diagram illustrating an FL notch position of a CTOD test.

FIG. **4**B is a schematic diagram illustrating an IC notch position of a CTOD test.

FIG. **5** is a diagram illustrating a relationship between a steel composition hardness parameter CeqH and a CTOD (δc) value in an IC zone at −60° C.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, the present invention will be described in detail.

According to the investigation of the inventors, for sufficiently improving the CTOD property of the FL zone and IC zone at −60° C., in welding of a low heat input to a medium heat input (for example, 1.5 to 6.0 kJ/mm at a plate thickness of 50 mm), it is the most important to reduce oxide-based non-metallic inclusions, and it is essential to reduce the amount of O (oxygen in steel).

In the conventional technique, for obtaining a steel excellent in the CTOD property of the FL zone, as transformation nuclei of an intragranular ferrite (IGF), the oxide-based non-metallic inclusion represented by Ti-oxides is used and it is necessary to add O to some degree. According to the investigation of the inventors, for improving the CTOD property of the FL zone and the IC zone at −60° C., it is necessary to reduce the oxide-based non-metallic inclusion.

Due to the reduction of O, the IGF decreases, such that it is necessary to reduce an alloy element that deteriorates the CTOD property of the FL zone. FIG. **1** shows a relationship between a CTOD property ($T_{\delta c0.1(FL)}$) of FL-equivalent synthetic HAZ and a steel composition parameter P_{CTOD}. Here, the steel composition parameter P_{CTOD} expressed by an equation (1) is an empirical equation derived by testing a plurality of vacuum melted steels at an experimental laboratory and by analyzing the CTOD property ($T_{\delta c0.1(FL)}$) of FL-equivalent synthetic HAZ and a steel composition.

$$P_{CTOD}=[C]+[V]/3+[Cu]/22+[Ni]/67 \quad (1)$$

Here, [C], [V], [Cu], and [Ni] represent the amounts (mass %) of C, V, Cu, and Ni in steel, respectively. For example, when Cu is not contained in steel, the amount of Cu is 0%.

In regard to the FL-equivalent synthetic HAZ shown in FIG. **1**, based on findings obtained from a plurality of experiments, the CTOD property $T_{\delta c0.1(FL)}$ at −110° C. or less is a target level ($T_{\delta c.01(FL)}\leq-110°$ C.) as the structural steels. In the target level, in regard to an FL notch test of a practical welded joint of a steel plate having the thickness of 50 to 100 mm, it is possible to stably secure a CTOD (δc) value of 0.25 mm or more at −60° C. From FIG. **1**, in regard to the FL-equivalent synthetic HAZ, to maintain the $T_{\delta c0.1(FL)}$ at −110° C. or less, it can be seen that it is necessary to control the steel composition parameter P_{CTOD} to be 0.065% or less. In addition, as the CTOD (δc) value becomes large, the toughness (for example, energy absorption due to plastic strain) is high.

The FL-equivalent synthetic HAZ is a zone corresponding to a heat input of the FL zone of a specimen to which an FL-equivalent synthetic thermal cycle described below is performed. The FL-equivalent synthetic thermal cycle (Triple cycle) is performed with respect to a specimen of 10 mm×20 mm (cross-section) under the following conditions:

1st cycle: Maximum heating temperature 1400° C. (800 to 500° C. is cooled in 15 seconds)

2nd cycle: Maximum heating temperature 760° C. (760 to 500° C. is cooled in 22 seconds)

3rd cycle: Maximum heating temperature 500° C. (500 to 300° C. is cooled in 60 seconds)

As shown in FIG. **4**A, an FL notch **7** in a weld **2** is located in an FL zone **5** that is a boundary of an HAZ **4** and a WM **3**. In the following CTOD test by the FL notch, the relationship between a load and an opening displacement of the FL zone **5** is measured.

The specimen is evaluated by a CTOD test of BS 5762 method (British Standards) and thereby $T_{\delta c0.1(FL)}$ of FIG. **1** is obtained. Here, the $T_{\delta c0.1(FL)}$ is a temperature (° C.) where the lowest value of the CTOD (δc) values, which are obtained using three specimens at each test temperature, exceeds 0.1 mm. In addition, when considering the effect of plate thickness in the CTOD test, in regard to the FL notch section (FL zone) of the practical welded joint of the steel plate having the thickness of 50 to 100 mm, it is necessary to maintain the $T_{\delta c0.1(FL)}$ at −110° C. or less as described above so that the CTOD (δc) value of 0.25 mm or more is stably secured at −60° C.

In addition, the inventors found that the reduction of hardness is effective, in addition to the reduction of oxygen in steel, in order to improve the CTOD property of the IC zone.

FIG. **2** shows a relationship between the CTOD property of a specimen which is subjected to an ICHAZ (intercritical HAZ)-equivalent synthetic thermal cycle and ICHAZ-equivalent synthetic HAZ hardness. In addition, FIG. **3** shows a relationship between a steel composition hardness parameter CeqH and an ICHAZ-equivalent synthetic HAZ hardness.

Here, in order to maintain the $T_{\delta c0.1(FL)}$ of the ICHAZ-equivalent synthetic HAZ (cross-section: 10 mm×20 mm) at −110° C. or less, it is necessary to maintain the HAZ hardness (Vickers hardness test under a load of 10 kgf) at 176 Hv or less. Therefore, from FIG. **3**, it is necessary to control the steel composition hardness parameter CeqH at 0.235% or less. In order to further lower the hardness, it is preferable that the steel composition hardness parameter CeqH is 0.225% or less.

In addition, as a fracture toughness test method, a CTOD test of BS 5762 method (British Standards) is adopted. In addition, ICHAZ-equivalent synthetic thermal cycle conditions (Triple cycle) are as follows:

1st cycle: Maximum heating temperature 950° C. (800 to 500° C. is cooled in 20 seconds)

2nd cycle: Maximum heating temperature 770° C. (770 to 500° C. is cooled in 22 seconds)

3rd cycle: Maximum heating temperature 450° C. (450 to 300° C. is cooled in 65 seconds)

As shown in FIG. **4**B, an IC notch **8** in the weld **2** is located at an IC zone (ICHAZ) **6** that is a boundary of a base metal **1** and the HAZ **4**. In a CTOD test by the IC notch, the relationship between a load and the opening displacement of the IC zone **6** is measured.

Here, the steel composition hardness parameter CeqH is an empirical equation obtained by a multiple regression of a property of steel (HAZ hardness) and a steel composition, and is defined as follows:

$$CeqH=[C]+[Si]/4.16+[Mn]/14.9+[Cu]/12.9+[Ni]/105+1.12[Nb]+[V]/1.82 \quad (2)$$

In addition, [C], [Si], [Mn], [Cu], [Ni], [Nb], and [V] are the amounts (mass %) of C, Si, Mn, Cu, Ni, Nb, and V in steel, respectively. For example, when Cu is not contained in steel, the amount of Cu is 0%.

Even when the P_{CTOD} and CeqH are limited as described above, if the amount of each alloy element contained in steel is not appropriately controlled, it is difficult to produce a steel having both high strength and an excellent CTOD property.

Hereinafter, the limitation range and a reason for limitation of the steel composition will be described. Here, the described % is a mass %. In addition to the steel composition parameter P_{CTOD} and steel composition hardness parameter CeqH, the steel composition is limited as described below, such that it is possible to obtain a steel for welded structure in which all of the CTOD (δc) value in the FL zone at −60° C. and the CTOD (δc) value in the IC zone at −60° C., which are obtained by the CTOD test of the BS 5762 method, are 0.25 mm or more.

C: 0.015 to 0.045%

For obtaining sufficient strength, it is necessary to contain 0.015% or more of C. However, at a C content [C] exceeding 0.045%, a property of a welding HAZ deteriorates and the CTOD property at −60° C. is not sufficient. For this reason, the upper limit of the C content [C] is 0.045%. Therefore, the C content [C] is from 0.015 to 0.045%

Si: 0.05 to 0.20%

For obtaining an excellent HAZ toughness, it is preferable that the Si content [Si] is as small as possible. However, since the Al content [Al] is limited as described later, for deoxidation, the Si content [Si] is necessarily 0.05% or more. However, when the Si content [Si] exceeds 0.20%, the HAZ toughness deteriorates, therefore the upper limit of the Si content [Si] is 0.20%. Therefore, the Si content [Si] is 0.05 to 0.20%. For obtaining further excellent HAZ toughness, it is preferable that the Si content [Si] is 0.15% or less.

Mn: 1.5 to 2.0%

Mn is an inexpensive element that has a large effect on the optimization of a microstructure. In addition, it is unlikely that the HAZ toughness deteriorates due to the addition of Mn. Therefore, it is preferable that the additional amount of Mn is as large as possible. However, when the Mn content exceeds 2.0%, the ICHAZ hardness increases, and the toughness is deteriorated. Therefore, the upper limit of the Mn content [Mn] is 2.0%. In addition, when the Mn content [Mn] is less than 1.5%, since the effect of improving the microstructure is small, the lower limit of the Mn content [Mn] is 1.5%. Therefore, the Mn content [Mn] is from 1.5 to 2.0%. For further improving the HAZ toughness, it is preferable that the Mn content [Mn] is 1.55% or more, more preferably is 1.6% or more, and most preferably is 1.7% or more.

Ni: 0.10% to 1.50%

Ni is an element that does not deteriorate the HAZ toughness much and improves the strength and toughness of the base metal, and does not increase the ICHAZ hardness much. However, Ni is an expensive alloy element, and when contained in steel excessively, Ni may generate surface cracks. Therefore, the upper limit of the Ni content [Ni] is 1.50%. On the other hand, in order to have the above-described effect of the addition of Ni sufficiently, it is necessary to contain at least 0.10% of Ni. Therefore, the Ni content [Ni] is from 0.10 to 1.50%. For improving the strength and toughness of the base metal without increasing the ICHAZ hardness much, it is preferable that the Ni content [Ni] is 0.20% or more, more preferably is 0.30% or more, and most preferably is 0.40 or 0.51% or more. In addition, for reliably preventing surface cracks, it is preferable that the Ni content [Ni] is 1.20% or less, and more preferably is 1.0% or less. In a case where the strength and toughness of the base metal can be secured by the addition of other elements, it is most preferable that the Ni content [Ni] is 0.80% or less for further securing economic efficiency. In addition, as described later, in order to suppress Cu cracking of a slab when Cu is added, it is preferable that the Ni content [Ni] is equal to half or more of the Cu content [Cu].

P: 0.008% or less (including 0%)

S: 0.005% or less (including 0%)

P and S are elements that decrease the toughness and are contained as unavoidable impurities. Therefore, it is preferable to decrease the P content [P] and the S content [S] so as to secure the toughness of the base metal and the HAZ toughness. However, there are restrictions of industrial production, such that the upper limits of the P content [P] and the S content [S] are 0.008% and 0.005%, respectively. For obtaining further excellent HAZ toughness, it is preferable that the P content [P] is limited to 0.005% or less, and the S content [S] is limited to 0.003% or less.

Al: 0.004% or Less (Excluding 0%)

Since it is necessary to generate Ti-oxides, it is preferable that the Al content [Al] is as small as possible. However, there are restrictions of industrial production, such that the upper limit of the Al content [Al] is 0.004%.

Ti: 0.005 to 0.015%

Ti generates Ti-oxides and makes the microstructure fine. However, when the Ti content [Ti] is too much, Ti generates TiC and thereby deteriorates the HAZ toughness. Therefore, the appropriate range of Ti content [Ti] is 0.005 to 0.015%. For further improving the HAZ toughness, it is preferable that the Ti content [Ti] is 0.013% or less.

Nb: 0.005% or Less (Including 0%)

Nb may be contained as an impurity, and improves the strength and toughness of the base metal, but decreases the HAZ toughness. The range of the Nb content [Nb] not significantly decreasing the HAZ toughness is 0.005% or less. Therefore, the Nb content [Nb] is limited to 0.005% or less. For further improving the HAZ toughness, it is preferable that the Nb content [Nb] is limited to 0.001% or less (including 0%).

O: 0.0015 to 0.0035%

It is essential that the O content [O] is 0.0015% or more to secure the generation of Ti-oxides as IGF nuclei of the FL zone. However, when the O content [O] is too high, the size of the oxides and number thereof become excessive, whereby the CTOD property of the IC zone deteriorates. Therefore, the O content [O] is limited to the range of 0.0015 to 0.0035%. For obtaining further excellent HAZ toughness, it is preferable that the O content [O] is 0.0030% or less, and more preferably is 0.0028% or less.

N: 0.002 to 0.006%

N is necessary to generate Ti-nitrides. However, when the N content [N] is less than 0.002%, the effect of generating Ti-nitrides is small. In addition, when the N content [N] exceeds 0.006%, surface cracks are generated when producing a slab, such that the upper limit of the N content [N] is 0.006%. Therefore, the N content [N] is from 0.002 to 0.006%. For obtaining further excellent HAZ toughness, it is preferable that the N content [N] is 0.005% or less.

Cu: 0.24% or Less (Including 0%)

Cu is an element that improves the strength and toughness of the base metal without deteriorating the HAZ toughness much, and does not increase the ICHAZ hardness much. Therefore, Cu may be added as necessary. However, Cu is a relatively expensive alloy element and the above-described effect is low compared to Ni. When Cu is added too excessively, the possibility of the Cu cracking of a slab is increased, such that the Cu content [Cu] is limited to 0.24% or less. Furthermore, when Cu is added to steel or is contained in steel as an impurity, for the prevention of the Cu cracking of a slab, it is preferable that the Cu content [Cu] is double or less of the Ni content [Ni]. In addition, since the solubility limit of Cu into ferrite (αFe) is small, ϵCu precipitates in the weld HAZ depending on a thermal history during welding and thereby there is a possibility of low temperature toughness decreasing. Therefore, it is preferable that the Cu content [Cu] is limited to 0.20% or less, and more preferably is 0.10% or less. If the strength of steel is sufficiently secured by an element such as C, Mn, and Ni, it is not necessarily necessary to add Cu. Even when Cu is selectively added for reasons of strength, it is preferable to limit the Cu content [Cu] to be as small as possible. Therefore, it is most preferable that Cu content [Cu] is 0.03% or less.

V: 0.020% or Less (Including 0%)

V is effective in improving the strength of the base metal. Therefore, V may be added as necessary. However, when V exceeding 0.020% is added, the HAZ toughness is largely decreased. Therefore, the V content [V] is limited to 0.020% or less. For sufficiently suppressing the HAZ toughness, it is preferable that the V content [V] is limited to 0.010% or less. If the strength of steel is sufficiently secured by an element such as C, Mn, and Ni, it is not necessarily necessary to add V. Even when V is selectively added for reasons of strength, it is preferable to limit the V content [V] to be as small as possible. Therefore, it is more preferable that V content [V] is 0.005% or less.

The steel for welded structure according to the present invention contains the above-described chemical components or these chemical components are limited, and the balance includes Fe and unavoidable impurities. However, the steel plate according to the present invention may contain other alloy elements as elements for the purpose of further improving corrosion resistance and hot workability of the steel plate itself or as unavoidable impurities from auxiliary raw material such as scrap, in addition to the above-described chemical components. However, in order to allow the above-described effects (improvement in toughness of the base metal or the like) of the above-described chemical component (Ni or the like) to be sufficiently exhibited, it is preferable that other alloy elements (Cr, Mo, B, Ca, Mg, Sb, Sn, As, and REM) are limited as described below. Each amount of the alloy elements includes 0%.

Cr decreases the HAZ toughness, such that it is preferable that the Cr content [Cr] is 0.1% or less, more preferably is 0.05% or less, and most preferably is 0.02% or less.

Mo decreases the HAZ toughness, such that it is preferable that the Mo content [Mo] is 0.05% or less, more preferably is 0.03% or less, and most preferably is 0.01% or less.

B increases the HAZ hardness, decreases the HAZ toughness, such that it is preferable that the B content [B] is 0.0005% or less, more preferably is 0.0003% or less, and most preferably is 0.0002% or less.

Ca has an effect of suppressing the generation of the Ti-oxides, such that it is preferable that the Ca content [Ca] is less than 0.0003%, and more preferably is less than 0.0002%.

Mg has an effect of suppressing the generation of the Ti-oxides, such that it is preferable that the Mg content [Mg] is less than 0.0003%, and more preferably is less than 0.0002%.

Sb deteriorates the HAZ toughness, such that it is preferable that the Sb content [Sb] is 0.005% or less, more preferably is 0.003% or less, and most preferably is 0.001% or less.

Sn deteriorates the HAZ toughness, such that it is preferable that the Sn content [Sn] is 0.005% or less, more preferably is 0.003% or less, and most preferably is 0.001% or less.

As deteriorates the HAZ toughness, such that it is preferable that the As content [As] is 0.005% or less, more preferably is 0.003% or less, and most preferably is 0.001% or less.

REM has an effect of suppressing the generation of the Ti-oxides, such that it is preferable that the REM content [REM] is 0.005% or less, more preferably is 0.003% or less, and most preferably is 0.001% or less.

As described above, the steel for welded structure according to the present invention contains the above-described chemical components as steel composition or these chemical components are limited, and the balance is composed of Fe and unavoidable impurities. However, since the steel for welded structure according to the present invention is used as a structural material, it is preferable that the minimum dimension (for example, plate thickness) of the steel is 6 mm or more. When considering usage as the structural material, the minimum dimension (for example, plate thickness) of the steel may be 100 mm or less.

The steel for welded structure may be produced by the producing method described below for further reliably obtaining the CTOD property according to the present invention. In a producing method of the steel for welded structure according to the present invention, the steel of which each amount of the elements and each of the parameters (P_{CTOD} and CeqH) are limited is used.

In a producing method of a steel for welded structure according to an embodiment of the present invention, a slab is produced from the above-described steel (molten steel) by a continuous casting method. In the continuous casting method, the cooling rate (solidification rate) of the molten steel is fast, and it is possible to generate large quantities of fine Ti-oxides and Ti-nitrides in the slab.

When the slab is rolled, it is necessary that the reheating temperature of the slab is 950 to 1100° C. When the reheating temperature exceeds 1100° C., the Ti-nitrides becomes coarse and thereby the toughness of the base metal deteriorates and it is difficult to improve the HAZ toughness.

In addition, when the reheating temperature is less than 950° C., rolling force becomes large, and thereby productivity is deteriorated. For this reason, the lower limit of the reheating temperature is 950° C. Therefore, it is necessary to perform the reheating to a temperature of 950 to 1100° C.

Next, after the reheating, a thermo-mechanical control process is performed. In the thermo-mechanical control process, the rolling temperature is controlled in a narrow range according to a steel composition and water-cooling is performed, if necessary. Through the thermo-mechanical control process, the refining of austenite grains and the refining of the microstructure can be performed and thereby the strength and toughness of the steel can be improved. It is preferable to control the thickness (minimum dimension) of the final steel (for example, steel plate) to be 6 mm or more through the rolling.

Through the thermo-mechanical control process, it is possible to produce the steel having HAZ toughness when welding but also sufficient toughness of the base metal.

As the thermo-mechanical control process, for example, a method of controlled rolling, a method of a combination of controlled rolling and accelerated cooling (controlled rolling—accelerated cooling), and a method of directly quenching after the rolling and tempering (quenching immediately after the rolling—tempering) may be exemplified. It is preferable that the thermo-mechanical control process is performed by the method by the combination of the controlled rolling and the accelerated cooling. In addition, after producing the steel, even when the steel is reheated to a temperature below Ar_3 transformation point for the purpose of dehydrogenation or optimization of strength, the property of the steel is not damaged.

EXAMPLES

Hereinafter, the present invention will be described based on examples and comparative examples.

Using a converter, continuous casting, and rolling process, a steel plate having various kinds of steel compositions was produced, and a tensile test on the strength of the base metal and a CTOD test on a welded joint were performed.

The welded joint used for the CTOD test was manufactured by a weld heat input of 4.5 to 5.0 kJ/mm using submerged arc welding (SAW) method used in a general test welding. As shown in FIGS. **4**A and **4**B, the FL zone **5** of the welded joint was formed by K-groove so that fusion lines (FL) **9** are substantially orthogonal to the end surface of the steel plate.

In the CTOD test, a specimen having a cross sectional size of t (plate thickness)×2t was used and a notch corresponding to 50% fatigue crack was formed in the specimen. As shown in FIGS. **4**A and **4**B, notch positions (FL notch **7** and IC notch **8**) are the FL zone (boundary of the WM **3** and HAZ **4**) **5** and the IC zone (boundary of the HAZ **4** and BM **1**) **6**. In the CTOD test, the FL notch **7** and the IC notch **8** were tested at −60° C. each time (5 times each, and 10 times in total).

Tables 1 and 2 show chemical compositions of the steels and Tables 3 and 4 show production conditions of the steel plate (base metal), the properties of the base metal (BM), and the properties of the welded joint.

In addition, symbols of a heat treatment method are as follows in Tables 3 and 4:

CR: Controlled-rolling (rolling at an optimal temperature range for improving the strength and toughness of the steel)

ACC: Controlled-rolling—accelerated cooling (the steel was water-cooled to a temperature range of 400 to 600° C. after controlled rolling, and then was air-cooled)

DQ: Quenching immediately after the rolling—tempering (the steel was quenched to 200° C. or less immediately after the rolling and then was tempered)

In addition, in regard to the results of the CTOD test of the welded joint in Tables 3 and 4, δc (av) represents an average value of CTOD values for five tests, and δc (min) represents the minimum value among the CTOD values for five tests.

In examples 1 to 7 and 16 to 30, yield strength (YS) was 432 N/mm^2 (MPa) or more, tensile strength was 500 N/mm^2 (MPa) or more, and the strength of the base metal was sufficient. In regard to a CTOD value (δc) at −60° C., the minimum value δc (min) of the CTOD value in the FL notch was 0.43 mm or more, the minimum value Sc (min) of the CTOD value in the IC notch was 0.60 mm or more, and the fracture toughness was excellent.

On the other hand, in comparative examples, the steel had the same strength as that in the examples, but the CTOD value was poor and thereby it was not suitable for used as a steel in a harsh environment.

In comparative examples 8 and 31, the C content in the steel was high, and the steel composition parameter P_{CTOD} and the steel composition hardness parameter CeqH were also high. Therefore, both of the CTOD value of the FL notch and the CTOD value of the IC notch were low.

In comparative examples 9 and 32, the Mn content in the steel was high and the steel composition hardness parameter CeqH was high. Therefore, especially, the CTOD value of the IC notch was low.

In comparative examples 10 and 33, the Al content in the steel was high. Therefore, especially, the microstructure control of the FL zone was insufficient and the CTOD value of the FL notch was low.

In comparative examples 11 and 34, the Nb content in the steel was high. Therefore, especially, the CTOD value of the IC notch was low.

In comparative examples 12 and 35, the Si content in the steel was high and the steel composition hardness parameter CeqH was high. Therefore, especially, the CTOD value of the IC notch was low.

In comparative examples 13 and 36, the V content in the steel was high, and the steel composition parameter P_{CTOD} and the steel composition hardness parameter CeqH were high. Therefore, both of the CTOD value of the FL notch and the CTOD value of the IC notch were low.

In comparative example 14, the Cu content in the steel was high. Therefore, cracks (Cu cracking) were generated at the time of hot rolling, and it was difficult to produce the steel. In particular, since an element for suppressing the Cu cracking from being generated was not added, as shown in Table 3, it was impossible to perform the CTOD test of the welded joint.

In comparative example 37, the O content in the steel was high. Therefore, both the CTOD value of the FL notch and the CTOD value of the IC notch were low.

In comparative example 15, the steel composition parameter CeqH was high. Therefore, the CTOD value of the IC notch was low.

In the above-described comparative examples 8 to 14 and 31 to 37, in regard to the CTOD value (δc) at −60° C., the minimum value δc(min) of the CTOD value at the FL notch was less than 0.25 mm, the minimum value δc(min) of the CTOD value at the IC notch was less than 0.25 mm, and the fracture toughness was not sufficient. In addition, in the above-described comparative example 15, in regard to the CTOD value (δc) at −60° C., since the minimum value δc (min) of the CTOD value at the FL notch was 0.25 mm or more, but the minimum value δc (min) of the CTOD value at the IC notch was less than 0.25 mm, the fracture toughness was not sufficient.

FIG. **5** shows the result of putting together the relationship between the steel composition hardness parameter CeqH and the CTOD (δc) value of the IC zone at −60° C. shown in Tables 1 to 4. As shown in FIG. **5**, when each component in the steel and the steel composition parameter P_{CTOD} satisfied the above-described conditions, it was possible to produce a steel for which the minimum value δc (min) of the CTOD value at the IC notch was 0.25 mm or more, by suppressing the steel composition hardness parameter CeqH to 0.235% or less. In addition, even when the steel composition hardness parameter CeqH was 0.235% or less, when each component in the steel and the steel composition parameter P_{CTOD} did not satisfy the above-described conditions, it was impossible to produce the steel of which the minimum value δc (min) of the CTOD value was 0.25 mm or more (for example, comparative examples 10, 11, 14, 33, 34, and 37).

TABLE 1

Classification	steel	Chemical composition (mass %) C	Si	Mn	Ni	P	S	Al	Ti	Nb	O	N	Cu	V	P_{CTOD}	CeqH
Examples	1	0.031	0.09	1.69	0.26	0.005	0.002	0.004	0.012	0.000	0.0018	0.0040		0.004	0.036	0.171
	2	0.036	0.10	1.56	0.30	0.005	0.003	0.002	0.010	0.003	0.0029	0.0037	0.06		0.043	0.172
	3	0.038	0.13	1.58	0.19	0.004	0.001	0.003	0.010	0.000	0.0024	0.0053	0.16	0.005	0.050	0.192
	4	0.041	0.06	1.54	0.20	0.005	0.004	0.003	0.011	0.001	0.0020	0.0038	0.23		0.054	0.179
	5	0.044	0.05	1.51	0.13	0.005	0.002	0.003	0.010	0.000	0.0023	0.0042	0.11		0.051	0.167
	6	0.039	0.07	1.55	0.19	0.006	0.003	0.002	0.010	0.000	0.0025	0.0041			0.042	0.162
	7	0.040	0.07	1.56	0.13	0.005	0.002	0.003	0.009	0.003	0.0021	0.0039		0.008	0.045	0.167
Comparative Examples	8	0.058	0.18	1.82	0.22	0.005	0.003	0.003	0.012	0.000	0.0029	0.0035	0.39		0.079	0.256
	9	0.039	0.20	2.15	0.30	0.005	0.002	0.002	0.009	0.000	0.0027	0.0029	0.28		0.056	0.256
	10	0.030	0.19	1.88	0.16	0.004	0.003	0.026	0.013	0.001	0.0030	0.0030	0.15		0.039	0.215
	11	0.040	0.15	1.90	0.34	0.005	0.002	0.003	0.010	0.009	0.0029	0.0024	0.35		0.061	0.234
	12	0.035	0.39	1.89	0.28	0.004	0.003	0.003	0.010	0.001	0.0024	0.0026	0.32		0.054	0.283
	13	0.041	0.18	1.75	0.21	0.004	0.003	0.002	0.010	0.000	0.0024	0.0026	0.30	0.029	0.067	0.243
	14	0.034	0.11	1.69	0.15	0.004	0.003	0.002	0.009	0.002	0.0026	0.0025	0.45		0.057	0.210
	15	0.043	0.17	1.92	0.51	0.004	0.003	0.003	0.010	0.003	0.0028	0.0028	0.14	0.016	0.062	0.241

TABLE 2

Classification	Steel	Chemical composition (mass %) C	Si	Mn	Ni	P	S	Al	Ti	Nb	O	N	Cu	V	P_{CTOD}	CeqH
Examples	16	0.015	0.13	1.97	1.47	0.005	0.003	0.003	0.009	0.000	0.0019	0.0038	0.12	0.000	0.042	0.202
	17	0.018	0.08	1.95	1.40	0.004	0.002	0.003	0.011	0.000	0.0022	0.0041	0.08	0.018	0.049	0.198
	18	0.020	0.11	1.86	1.35	0.006	0.002	0.002	0.008	0.002	0.0024	0.0036		0.003	0.041	0.186
	19	0.021	0.16	1.92	1.31	0.005	0.003	0.004	0.010	0.000	0.0016	0.0045		0.000	0.041	0.201
	20	0.023	0.19	1.75	1.29	0.003	0.001	0.003	0.010	0.000	0.0028	0.0029		0.002	0.043	0.200
	21	0.029	0.10	1.63	1.22	0.006	0.003	0.004	0.011	0.000	0.0032	0.0025		0.012	0.051	0.181
	22	0.031	0.09	1.69	1.08	0.005	0.002	0.004	0.012	0.000	0.0018	0.0040		0.004	0.048	0.179
	23	0.032	0.07	1.61	1.20	0.004	0.002	0.003	0.009	0.002	0.0017	0.0033	0.05	0.000	0.052	0.172
	24	0.035	0.10	1.80	1.13	0.004	0.002	0.002	0.008	0.000	0.0025	0.0028		0.000	0.052	0.191
	25	0.036	0.10	1.56	0.96	0.005	0.003	0.002	0.010	0.003	0.0029	0.0037	0.16	0.000	0.058	0.186
	26	0.038	0.13	1.58	1.01	0.004	0.001	0.003	0.010	0.000	0.0024	0.0053		0.005	0.055	0.188
	27	0.040	0.12	1.65	0.88	0.006	0.003	0.003	0.009	0.000	0.0022	0.0022		0.001	0.053	0.189
	28	0.041	0.06	1.54	0.82	0.005	0.004	0.003	0.011	0.001	0.0020	0.0038	0.15	0.000	0.060	0.178
	29	0.044	0.05	1.51	0.73	0.005	0.002	0.003	0.010	0.000	0.0023	0.0042		0.000	0.055	0.164
	30	0.038	0.07	1.59	0.73	0.005	0.002	0.003	0.011	0.002	0.0022	0.0038	0.11	0.008	0.057	0.181
Comparative Examples	31	0.058	0.18	1.82	1.11	0.005	0.003	0.003	0.012	0.000	0.0029	0.0035	0.14	0.000	0.081	0.245
	32	0.039	0.20	2.15	0.95	0.005	0.002	0.002	0.009	0.000	0.0027	0.0029		0.000	0.053	0.240
	33	0.030	0.19	1.88	1.01	0.004	0.003	0.026	0.013	0.001	0.0030	0.0030		0.000	0.045	0.211
	34	0.040	0.15	1.90	1.09	0.005	0.002	0.003	0.010	0.009	0.0029	0.0024	0.18	0.000	0.064	0.228
	35	0.035	0.39	1.89	0.92	0.004	0.003	0.003	0.010	0.001	0.0024	0.0026		0.000	0.049	0.264
	36	0.041	0.18	1.75	1.03	0.004	0.003	0.002	0.010	0.000	0.0024	0.0026	0.16	0.029	0.073	0.240
	37	0.034	0.11	1.69	0.28	0.004	0.003	0.002	0.009	0.002	0.0041	0.0039		0.000	0.038	0.177

TABLE 3

Classification	Steel	Heating temperature (° C.)	Heat treatment method	Plate thickness (mm)	Strength of base metal YS (MPa)	TS (MPa)	CTOD value of welded joint (test temperature: −60° C.) FL notch δc(av) (mm)	FL notch δc(min) (mm)	IC notch δc(av) (mm)	IC notch δc(min) (mm)
Examples	1	1060	DQ	60	438	509	0.66	0.53	0.90	0.80
	2	1050	ACC	50	467	535	0.76	0.53	0.94	0.78
	3	1060	ACC	50	440	514	0.73	0.52	0.96	0.81
	4	1050	ACC	60	437	507	0.77	0.49	0.90	0.73
	5	1100	ACC	60	444	511	0.75	0.47	0.84	0.60
	6	1080	ACC	50	458	538	0.79	0.48	0.88	0.63
	7	1080	ACC	60	451	524	0.76	0.45	0.86	0.59
Comparative Examples	8	1100	ACC	50	449	529	0.09	0.04	0.08	0.03
	9	1050	ACC	50	444	525	0.45	0.07	0.11	0.04
	10	1080	ACC	50	440	522	0.08	0.02	0.14	0.03
	11	1050	ACC	40	436	516	0.37	0.16	0.09	0.03
	12	1080	ACC	50	434	518	0.41	0.23	0.07	0.04
	13	1100	ACC	50	445	532	0.06	0.04	0.08	0.03
	14	1050	ACC	60	437	531	—	—	—	—
	15	1050	ACC	60	439	542	0.68	0.37	0.12	0.05

TABLE 4

Classification	Steel	Heating temperature (° C.)	Heating treatment method	Plate thickness (mm)	Strength of base metal YS (MPa)	TS (MPa)	CTOD value of welded joint (test temperature: −60° C.) FL notch δc(av) (mm)	δc(min) (mm)	IC notch δc(av) (mm)	δc(min) (mm)
Examples	16	1080	ACC	45	448	520	0.78	0.47	0.93	0.63
	17	1100	ACC	45	453	523	0.76	0.43	0.91	0.75
	18	1060	ACC	50	444	515	0.81	0.49	0.87	0.65
	19	1100	CR	50	467	522	0.80	0.52	0.92	0.74
	20	1000	ACC	60	443	509	0.84	0.62	0.89	0.71
	21	1050	DQ	50	436	505	0.73	0.54	0.95	0.83
	22	1060	DQ	60	442	514	0.66	0.53	0.90	0.80
	23	1000	ACC	60	464	527	0.79	0.58	0.94	0.82
	24	1100	DQ	45	460	532	0.77	0.50	0.95	0.81
	25	1050	ACC	50	471	540	0.76	0.53	0.94	0.78
	26	1060	ACC	50	444	519	0.73	0.52	0.96	0.81
	27	980	DQ	50	457	525	0.68	0.49	0.92	0.79
	28	1050	ACC	60	441	512	0.77	0.49	0.90	0.73
	29	1100	ACC	60	448	516	0.75	0.47	0.84	0.60
	30	1100	ACC	50	453	527	0.76	0.50	0.86	0.63
Comparative Examples	31	1100	ACC	50	453	534	0.09	0.04	0.08	0.03
	32	1050	ACC	50	448	530	0.45	0.07	0.11	0.04
	33	1080	ACC	50	444	527	0.16	0.05	0.13	0.05
	34	1050	ACC	40	440	521	0.37	0.16	0.08	0.03
	35	1080	ACC	50	438	523	0.26	0.23	0.08	0.04
	36	1100	ACC	50	449	537	0.06	0.04	0.09	0.03
	37	1050	ACC	60	392	479	0.09	0.03	0.10	0.04

It is possible to provide a steel for welded structure excellent in a CTOD property of a heat-affected zone in welding of a low heat input to a medium heat input, and a producing method thereof.

What is claimed is:

1. A steel for a welded structure, comprising the following composition:

by mass %,

C at a C content [C] of 0.015 to 0.045%;

Si at a Si content [Si] of 0.05 to 0.20%;

Mn at a Mn content [Mn] of 1.5 to 2.0%;

Ni at a Ni content [Ni] of 0.73% to 1.50%;

Ti at a Ti content [Ti] of 0.005 to 0.015%;

O at an O content [O] of 0.0015 to 0.0032%; and

N at a N content [N] of 0.002 to 0.006%,

and a balance composed of Fe and unavoidable impurities, wherein, a P content [P] is limited to 0.008% or less,

a S content [S] is limited to 0.005% or less,

an Al content [Al] is limited to 0.004% or less,

a Nb content [Nb] is limited to 0.005% or less,

a Cu content [Cu] is limited to 0.24% or less,

a V content [V] is limited to 0.020% or less, and

a steel composition parameter P_{CTOD} of a following equation (3) is 0.065% or less, and a steel composition hardness parameter CeqH of a following equation (4) is 0.200% or less, where

$$P_{CTOD}=[C]+[V]/3+[Cu]/22+[Ni]/67 \quad (3)$$

$$CeqH=[C]+[Si]/4.16+[Mn]/14.9+[Cu]/12.9+[Ni]/105+1.12[Nb]+[V]/1.82 \quad (4),$$

and the steel for welded structure wherein a CTOD (dc min) value in an IC zone at −60° C., which is obtained by a CTOD test of BS 5762 method, is 0.59 mm or more.

2. The steel for welded structure according to claim **1**, wherein Cu is included, by mass %, at the Cu content [Cu] of 0.03% or less.

3. A producing method of a steel for welded structure, comprising:

continuously casting steel satisfying the steel composition according to claim **1** or **2** to manufacture a slab; and

heating the slab to a temperature of 950 to 1100° C. and then subjecting the slab to a thermo-mechanical control process.

4. The steel for welded structure according to claim **1**, wherein the composition contains: by mass %, O at an O content [O] of 0.0015 to 0.0028%.

5. The steel for welded structure according to claim **1**, wherein the steel composition hardness parameter CeqH is 0.191% or less.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,668,784 B2
APPLICATION NO. : 13/138119
DATED : March 11, 2014
INVENTOR(S) : Yoshiyuki Watanabe et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 1, line 57, change “large amount of 0” to -- large amount of O --;

Column 6, line 28, change “or Less” to -- or less --;

Column 7, line 1, change “or Less” to -- or less --;

Column 7, line 15, change “ϵCu” to -- εCu --;

Column 7, line 26, change “or Less” to -- or less --;

Column 9, line 61, change “value Sc” to -- value δc --.

Signed and Sealed this
Sixteenth Day of September, 2014

Michelle K. Lee

Deputy Director of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	:	8,668,784 B2	
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DATED	:	March 11, 2014	
INVENTOR(S)	:	Watanabe et al.	

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page:

The first or sole Notice should read --

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 22 days.

Signed and Sealed this
Twenty-ninth Day of September, 2015

Michelle K. Lee
Director of the United States Patent and Trademark Office